Physical Properties of Five Grain Dust Types

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Physical properties of grain dust derived from five grain types (soybean, rice, corn, wheat, and sorghum) were measured and reported. The grain dusts were obtained from dust collection systems of terminal grain handling facilities and were assumed to be representative of grain dust generated during the handling process. The physical properties reported were as follows: particle size distributions and surface area measurements using a Coulter Counter Model TAII; percent dust fractions less than 100 µm of whole dust; bulk density; particle density; and ash content.

Introduction

The Department of Agricultural Engineering, Texas Agricultural Experiment Station, Texas A&M University has been involved in the study of grain dust explosions and cyclone design for a number of years. Grain dust physical properties have been studied to assist in explaining phenomena associated with laboratory explosions using various dust fractions derived from different groups. In addition, cyclone efficiency evaluations and design criteria require substantial data on dust physical properties.

In order for grain dust explosions to occur, four ingredients must be present. These ingredients are fuel, confinement, ignition source, and oxygen. The fuel for a grain dust explosion is grain dust in suspension above the minimum explosive concentration (MEC). Containment is a requirement for an explosion to occur in that it allows a buildup of pressure resulting in rupture of the confinement. However, containment is also necessary to achieve the MEC of grain dust, which is in the range of 50 g/m^3 (1).

The dispensibility and combustion rates of dust are governed by chemical and physical properties of the dust involved. How easily and uniformly a dust is suspended into the air depends on its particle size distribution and density. The rate of combustion is highly dependent on the exposed surface area of dust that can readily react with oxygen. These physical properties are the key to defining dust explosibility and developing

are the key to defining dust explosibility and developing an explosion hazard indication.

Different laboratory techniques have been employed by various researchers in an effort to quantify dust characteristics. Plemons (2) and Martin (3) performed particle size analysis by wet sieving, dry sieving, and Coulter counter techniques. Wade, Hawk, and Watson (4) also used Coulter counter techniques to determine particle size distributions. A summary of a portion of the work done in this area is shown in Table 1.

By far, the most explosive grain dust fraction is that less than 100 µm (5). The smaller fractions of grain dust are most explosive because the surface area per unit mass increases as the particle size decreases. However, larger fractions (250–500 µm) in sufficient concentrations can be made to explode. The surface areas of grain dust have been determined by Deshpande and Matthews (6) and Martin (4). Each of these researchers used adsorption techniques and Martin also used a light obscuration method. Martin found that the surface area for grain dust varied from 0.6 to 0.9 m^2/g. Deshpande and Matthews found that the surface area for grain dust ranged from 0.6 to 1.96 m^2/g.

The bulk density and particle density affect the handling and conveying characteristics of particulate material. Chang and Martin (7) developed models to predict the density distribution and weight of grain dust in self-packed columns. They found that the bulk density of self-packed dust increased linearly as the depth of the pile increased. These tests were performed on wheat, sorghum, and corn dust. Figure 1 shows the relationship between the vertical density distribution of grain dust in a self-packed grain dust column.

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Table 1. Summary of past particle size analysis of grain dust.

Researcher	Techniques	Dusts	Mass mean diameter, μm
Plemons (3)	Coulter Counter Wet sieving Dry sieving	Rice Corn Soybean Wheat Sorghum	21.75[a] 19.57[a] 25.17[a] 32.97[a] 36.92[a]
Martin (4)	Coulter Counter Wet sieving Dry sieving Capture velocity	Soybean	30.00[b]
Wade (5)	Coulter Counter	Corn Soybean	13.70[c] 15.50[c]

[a]Mass mean diameter of whole grain dusts as determined by Coulter Counter techniques with a 400 μm apperature.
[b]Mass mean diameters of whole soybean dusts as determined by Coulter Counter techniques and read from graphical presentation of results.
[c]Mass mean diameters of whole corn and soybean dust as determined by Coulter Counter techniques.

Plemons and Parnell (8) and Martin (4) determined the particle densities of grain dusts using Beckman air pycnometers. Plemons and Parnell found the particle densities for rice, corn, wheat, soybean, and sorghum dust which range from 1.41 to 1.90 g/cm³ for wheat and soybean dust, respectively. Martin found the particle density of whole "grain" dust to be 1.49 g/cm³.
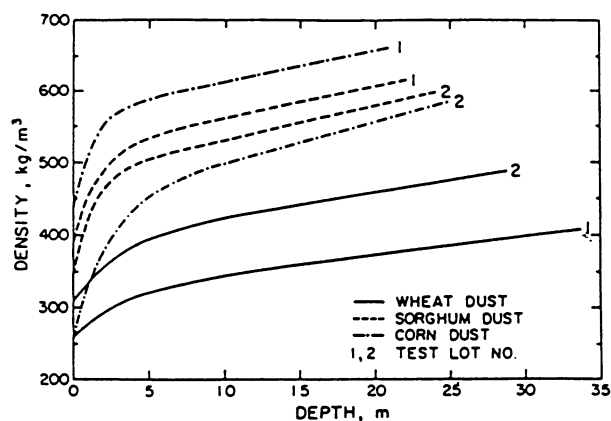

FIGURE 1. Vertical density distribution of grain dust in a self-packed dust column (7).

The percent of ash present in a grain dust sample is a measure of the inorganic material content and represents that fraction which is incombustible. Plemons and Parnell (8) tested wheat, corn, soybean, rice, and sorghum dust for ash content (Table 2).

Proper management of grain dust can be enhanced by increased knowledge of dust properties. The particle size, density, ash content, and surface area of grain dust particles affect the explosibility and handling characteristics of grain dust (4).

Table 2. Summary of past research on ash contents of grain dusts.

Dust	Ash content (dry basis), %	
	Plemons and Parnell (8)	Martin (4)
Soybean	32.86	12.1–40.5
Corn	1.88	4.1– 9.1
Wheat	12.20	7.9–28.5
Sorghum	7.5	
Rice	31.45	

Procedure and Results

Dust samples from five grains (soybeans, rice, corn, wheat, and sorghum) were obtained from baghouse filters of terminal elevators on the Texas Gulf Coast and stored in an environmental chamber until laboratory tests were performed. (A series of laboratory tests was performed to determine the particle size distribution, particle density, bulk density, ash content, and surface area of each of the five types of dust.)

Percent (by Weight) of Dust Less than 100 μm

The percent by weight of dust less than 100 μm is a measure of the mass of readily ignitable particles present in whole grain dust. This physical characteristic was determined using a wet sieving process performed on each of the five types of grain dust.

Approximately 1 g of whole dust was suspended in 25 mL of methanol. Separation was insured by placing the dust/methanol solution in an ultrasonic bath for 2 min. This solution was poured through a nylon filter screen with 100 μm openings, and filtrate was collected in small preweighed containers.

The containers holding the filtrate were placed in an oven for 24 hr at 66°C to allow complete evaporation of the methanol. The dried filtrate and containers were reweighed to determine the net weight of particulate less than 100 μm. Equation (1) was used to determine the percent of dust less than 100 μm present in whole dust:

$$PLT100 = \frac{W(p)}{W(w)} \times 100\%$$ (1)

where PLT100 = percent of dust (by weight) less than 100 μm present in whole dust, $W(p)$ = weight of dust passed through a 100-μm screen after methanol evaporation, and $W(w)$ = weight of initial whole dust sample.

Table 3. Percent by weight of grain dust less than 100 μm by wet sieving.

Dust	% < 100 μm	SD, %	CV, %
Soybean	50.6	1.53	2.95
Rice	44.2	2.20	4.99
Corn	54.1	3.30	6.10
Wheat	34.3	1.68	4.88
Sorghum	34.3	1.30	3.79

The means, standard deviations, and coefficients of variation for five samples of each of the five types of grain dusts are presented in Table 3. The results show that corn dust has the largest percentage (by weight) of dust less than 100 μm present in whole dust with 54.1%. Tests performed on sorghum and wheat dusts resulted in the lowest percentage of 34.3%.

Bulk Density and Particle Density

Just as whole grains have individual bulk densities and particle densities, the dusts generated from these grains also have characteristic bulk densities and par-

ticle densities. The bulk densities of each of the five grain dusts were determined by finding the weight of a known volume of grain dust. A preweighed container was completely filled with approximately 30 cm³ of grain dust. The net weight of the grain dust was found by placing the dust filled container on a Mettler Model P1000 top-loading scale. This procedure is currently being revised to provide for more accurate analysis of the bulk densities of grain dusts.

The particle densities of each of the five grain dusts were found by using a Beckman air compressor pycnometer, Model 930. Pycnometer procedures (9) were followed using a sample size of approximately 5 of whole grain dust. From the weight and resulting volume, the particle densities of each of the five grain dusts were calculated.

Results of the bulk density and particle density determinations are presented in Tables 4 and 5, respectively. The data represent three repetitions for each dust type. Sorghum dust is shown to have the largest bulk density and the smallest particle density. Conversely, soybean dust had the smallest bulk density and the largest particle density.

Particle Size Distributions (PSD)

Each type of grain dust has a unique particle size distribution which is affected by the parent type of grain and the dust collection used (8). The particle size distributions (PSD) of each of the five grain dusts were found by using the Coulter Counter (model TAII) techniques (10).

The electrolytic solution used to suspend the grain dust particles was a nonaqueous 5% lithium chloride/methanol solution. It was considered likely that the grain dust particles would absorb the more common isotonic aqueous solutions. The absorption of isotonic aqueous solutions by the dust particles could result in swelling, which would in turn produce erroneous particle size determinations.

Table 4. Bulk densities of whole grain dust.

Dust	Mean $\bar{X}$, g/cm³	SD, g/cm³	CV, %	MC wb, %[a]
Soybean	0.150	0.00500	3.33	6.40
Rice	0.221	0.00577	2.71	5.60
Corn	0.153	0.0137	8.50	7.00
Wheat	0.208	0.00436	1.92	7.80
Sorghum	0.308	0.0150	4.87	7.30

[a] Moisture content, % wet basis.

Table 5. Particle densities of whole grain dust using a Beckman air pycnometer, Model 930.

Dust	Mean $\bar{X}$, g/cm³	SD, g/cm³	CV, %	MC wb, %[a]
Soybean	1.69	0.0557	3.29	10.3
Rice	1.46	0.0200	1.37	6.47
Corn	1.50	0.0551	3.68	8.28
Wheat	1.48	0.0152	1.03	8.56
Sorghum	1.43	0.00557	0.403	12.2

[a] Moisture content, % wet basis.

PSDs of the five dust types are described by the mass median diameter and geometric standard deviation of the individual distributions in Table 6. Table 6 also contains the remaining information available from the Coulter Counter procedure, i.e., the mean, mode, skewness, and kurtosis of the particle size distributions.

Also available from the Coulter Counter procedure are the differential and cumulative histograms of each of the PSD. Figures 2 through 6 show the histograms for soybean, rice, corn, wheat, and sorghum dusts, respectively.
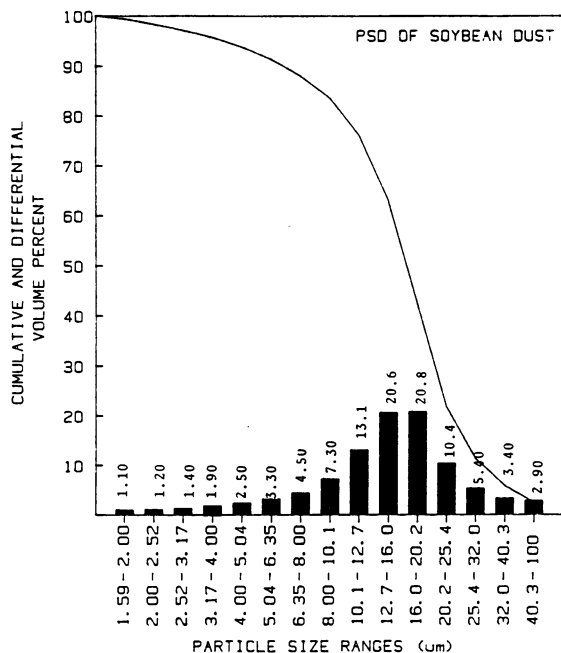

FIGURE 2.   Differential and cumulative histograms for the particle size distribution of soybean dust <100 μm.
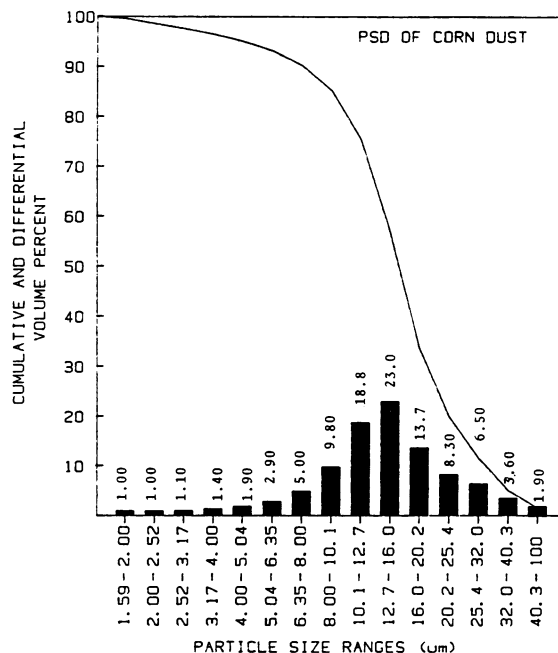

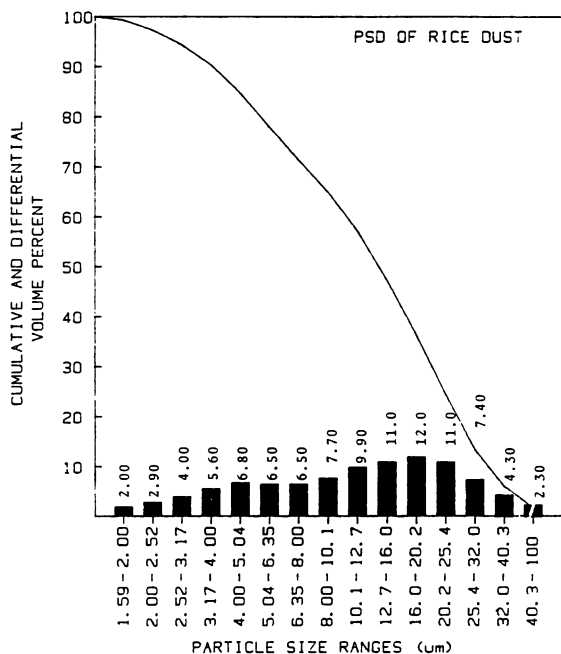FIGURE 4.   Differential and cumulative histograms for the particle size distribution of corn dust <100 μm.

FIGURE 3.   Differential and cumulative histograms for the particle size distribution of rice dust <100 μm.
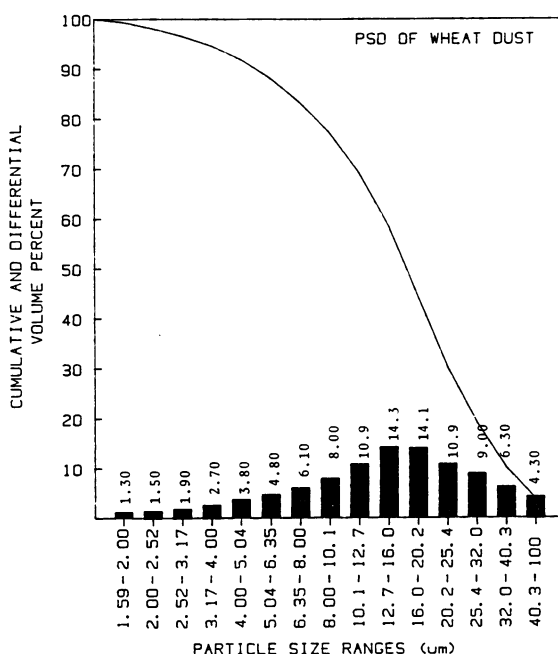

FIGURE 5.   Differential and cumulative histograms for the particle size distribution of wheat <100 μm.

Table 6. Particle size distributions of soybean, rice, corn, wheat, and sorghum dust, < 100 μm using the Coulter Counter, Model TAII.

	Soybean	Rice	Corn	Wheat	Sorghum
Mean, μm	13.6	10.7	13.2	13.4	14.0
Median, μm	14.8	12.1	13.6	14.7	15.7
Mode, μm	16.1	18.0	13.7	15.8	18.1
SD, μm	1.87	2.24	1.80	2.08	2.16
Skewness	−0.810	−0.830	−0.860	−0.790	−0.720
Kurtosis	1.90	2.58	1.69	2.34	2.96

Surface Area

Surface area is an important physical property related to the explosibility of grain dust (6). Traditional methods of surface area determination of particulate material, such as nitrogen adsorption, have been successfully utilized for inorganic material. However, grain dusts are largely composed of organic components and it was considered likely that organic dust would absorb nitrogen resulting in false surface area measurements. In an attempt to obtain accurate measurements of surface areas for soybean, rice, corn, wheat, and sorghum dust, the Coulter Counter procedure (10) was used.

Equation (2) was used to determine surface area, in square meters per gram of dust less than 100 μm, as a function of particle density, differential volume percentage, particle diameter, and an assumed particle shape for the grain dusts.

$$SA = \frac{Y_i(SF)}{100 \exp\{\log X_i + (\log 2)/6\}DS} \quad (2)$$

where SA = surface area (m²/g) of grain dust particles less than 100 μm, Y_i = differential volume percent in current range, X_i = diameter (μm) at lower edge of current range, DS = particle density (g/cm³), and SF = shape factor. The differential volume percentages and particle diameters were obtained directly from the PSD data and particle densities were determined as previously discussed.

The shape factor SF was determined by using a calibration material (zinc oxide) having a known surface area (as determined by nitrogen adsorption) and particle density (11). The differential volume percentages and particle diameters were obtained by determining the PSD of the calibration particles. The appropriate shape factors were subsequently calculated by using Eq. (2). The surface areas of each of the five types of grain dust were assumed to have a shape factor identical to that of the calibration particles.

The means, standard deviations, and coefficients of variation of the surface areas for three samples of each of the five types of grain dust are presented in Table 7. The surface area for rice dust less than 100 μm was greater than that of the other dusts. This is to be expected, since the rice dust exhibited the smallest mass mean diameter of the five types of grain dust.
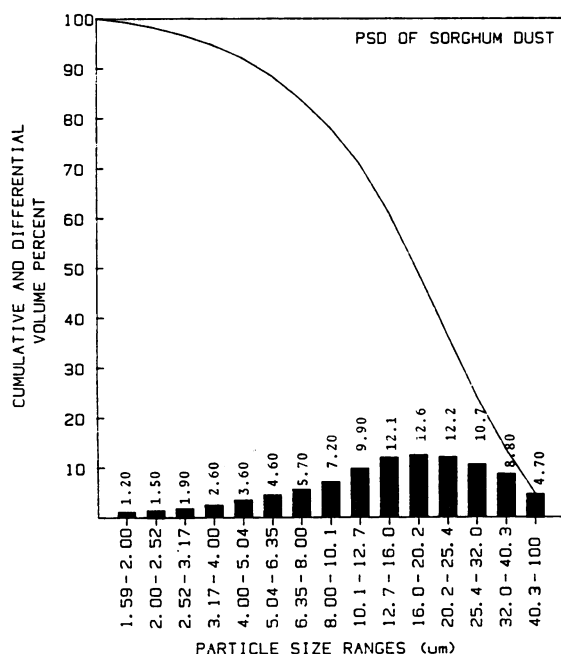
Ash Content

The percentage of ash present in a grain dust sample is a measure of the inorganic fraction present in whole grain dusts.

Ash contents were determined for each of the five grain dusts by using a baffle furnace procedure. A pre-weighed sample of grain dust was placed in a drying oven to remove the moisture. The dried sample of grain dust was weighed and placed in a baffle furnace for 120 min at 550°C. The samples were cooled in a desiccator before reweighing. The percentage of ash was calculated by using Eq. (3).

$$\% \text{ ash} = \frac{\text{Weight of ash}}{\text{Total weight of dry dust}} \times 100\% \quad (3)$$

FIGURE 6. Differential and cumulative histograms for the particle size distribution of sorghum dust <100 μm.

Table 7. Surface areas for soybean, rice, corn, wheat, and sorghum dusts < 100 μm by the Coulter Counter method, Model TAII.

Dust	$\bar{X}$, m²/g	SD, m²/g	CV, %
Soybean	0.869	0.003	0.37
Rice	1.092	0.055	5.05
Corn	0.826	0.006	0.74
Wheat	0.862	0.018	2.07
Sorghum	0.866	0.040	4.59

The means, standard deviations, and coefficients of variation of six samples of each of the five types of grain dust are presented in Table 8. Ash contents of the whole grain dusts ranged from 5.12% for soybean dust to over 30% for rice. This would indicate that rice dust contains a large amount of inorganic matter.

Table 8. Ash contents of soybean, rice, corn, wheat, and sorghum dusts using a baffle furnace.

Dust	Ash content, %	SD, %	CV, %
Soybean	5.2	0.223	4.35
Rice	30.6	0.414	1.36
Corn	12.0	0.173	1.40
Wheat	7.19	0.495	6.89
Sorghum	9.59	0.376	3.90

Conclusion

Physical properties of grain dust play an important role in explaining dust explosibility and handling characteristics. Analysis of interaction between these properties will aid in the development of an explosion hazard indicator and in the design and evaluation of dust handling/separation equipment.

Results of the laboratory analysis of wheat, corn, rice, soybean, and sorghum dust are as follows: bulk density, 0.150–0.308 g/cm^3; particle density, 1.43–1.69 g/cm^3; % < 100 μm (by weight), 34.3–50.6%; mass mean diameter (dust < 100 μm), 10.7–14 μm; ash content, 5.12–30.6%.

Future Research

A promising dust control method for grain elevators is the addition of oil to grain. Over one hundred elevators in the midwest are already applying mineral oil to all their grain and preliminary results have proven beneficial. The Food and Drug Administration has approved an additive level of 0.02% by weight food grade (white) mineral oil. Further research at Texas A&M University includes a computer simulation of the operation of elevator dust control systems for comparison of the cost of conventional dust control to oil additive costs. Also, grain samples taken at elevators using oil additives are being analyzed as to dust content and particle size distribution. These data will be used in future work concerning detection of the oil concentration on grain and effects of various concentrations of foreign matter.

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